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IS THE NEUTRON BOMB COMING?

– as translated from GERMAN

KOMMT DIE NEUTRONENBOMBE?

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Is the Neutron Bomb Coming?

Fred M. Kaplan

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The neutron bomb is the latest development in the apparently never ending search for new weapons, especially nuclear weapons, that can be used for highly specific purposes. Its official name is Enhanced Radiation Warhead (ERW). It was guarded as a secret for years and was disguised as a research and development project in ERDA (Energy Research and Development Administration). Its uncovering by reporters last summer stimulated a heated controversy which continues unabated.

In the event of war, the neutron bomb's task is to kill more people with a single warhead than with a conventional nuclear weapon. At the same time, the damage to buildings, agriculture and materiel is to be reduced to a minimum.

At present, the military seems to be seriously thinking about the use of tactical atomic weapons as a means of waging war. These thoughts and the well-known horrible biological effects of neutron radiation have roused resistance from many quarters.

The neutron bomb is the newest generation of tactical atomic weapons, intended for use in the event of a war in Europe, i.e., primarily in the territory of the Federal Republic of Germany. Accordingly, the various aspects of this weapon deserve a more detailed discussion, especially because the publicity about the neutron bomb has led to many legends and misunderstandings.

How did this bomb come into being? How does it work? What effects does it have? What are its military effects, and with what possible consequences? Can its production and its use be justified at all?

The history of the neutron bomb is bound up with the history of a specialized technology, technocratic interests, and political-strategic considerations. The idea of a neutron weapon is not new. It goes back to Edward Teller's concept of the hydrogen bomb in the late forties. By 1947 the U.S. Secretary of Defense was already writing about the possibility of using "enhanced radiation" as a weapon.

Some scientists at the Lawrence Livermore Laboratory, one of the leading weapons research labs in the U.S., worked on it and also pushed for their idea

in political circles during the fifties and sixties. Sam Cohen, one of Teller's students at the influential think-tank RAND Corporation, immersed himself in the concept in the middle of the fifties.

THE RISK OF AN ATOMIC COUNTERATTACK

At the beginning of the sixties, Secretary of Defense Robert S. McNamara called for a study of deterrent atomic weapons. On the basis of that study and various strategic considerations of NATO, he concluded that an atomic war would be a lost cause from the outset. The use of nuclear weapons would not necessarily turn out well for NATO in a war in Europe:

Entirely apart from reinforcement capabilities for manpower and conventional weapons, their use would result in a much greater demand for soldiers so as to be able to quickly replace the soldiers that would be wiped out by the thousands as a result of the Soviet nuclear counterattack.

Since the Warsaw Pact plans a step-by-step expansion of its attack troops while NATO prefers individual replacement within the existing structure of its divisions, an atomic war would probably be more advantageous only for the USSR, even if NATO possibly has more or "better" atomic weapons. Moreover, the risk of an expansion to a general atomic war between the U.S. and the USSR would be too great, especially for the following two reasons:

- The "fire crossover" from conventional to nuclear warfare is clearly evident to all. To decide between a tactical and a strategic atomic war would lead to ambiguities and thus to uncertainties, anxiety and, possibly, premature strategic nuclear strikes.
- Many Soviet atomic weapons are stationed inside the Soviet Union, some in the same places as the long-range intercontinental missiles. In the early stages of a tactical war there would be a great temptation to destroy those rocket sites on Soviet territory as a precautionary measure. That might precipitate a nuclear exchange between the superpowers.

Based on these analyses, McNamara decided to equip the armed forces with conventional non-nuclear weapons. He refused to finance a new generation of tactical atomic weapons, while promoting the "Lance" rockets which have a lower vulnerability due to their longer range.

The restraint against the modernization of deterrent atomic weapons persisted until James Schlesinger became Secretary of Defense. He was previously chairman

of the Atomic Energy Commission (later renamed ERDA and today part of the Department of Energy). Schlesinger turned out to be very open-minded about tactical atomic weapons. He included the development of new types of nuclear weapons in his program, partly also because of new technological advances, perhaps with the aim of improving the accuracy of long-range rocket guidance systems.

In the meantime, short-range defensive missiles had been developed in the middle of the sixties. They explode in the atmosphere and emit more neutron radiation than x-radiation. However, the SALT agreement of 1972 outlawed such missiles. After that, the scientists attempted to diminish the effect of the short-range missile warheads for use as tactical atomic weapons. That, in turn, was opposed to the interests of the Secretary of Defense.

Today, enhanced-radiation warheads (the neutron bomb) are being developed for the Lance missile and for 8-inch (ca. 20 cm) artillery shells. They are also planned for 155-mm projectiles. One of these warheads was already tested in an underground test near Las Vegas, Nevada. The version for the Lance missile is to have an explosive force of 1 kt (1 kiloton = 1000 tons of trinitrotoluene TNT). About 1 to 2 kt are planned for the 8-inch shell.

The effect of a nuclear explosion consists of the pressure effect (a shock wave with overpressure), thermal radiation, direct radiation (mainly neutron and gamma radiation) and residual radiation (decay products which produce radioactive fallout). The energy released in the explosion of a fission bomb divides into 50% pressure wave, 35% thermal radiation, 5% direct radiation and 10% residual radiation.

In a fusion reaction, 80% of the effect comes from the direct radiation. The fusion of deuterium and tritium (two heavy isotopes of hydrogen) is accompanied by the release of fast, high-energy neutrons. Their energy is 14 MeV (million electron-volts). In contrast, the neutrons from a fission explosion have an average energy of 2 MeV.

The neutrons are slowed down by residues from the bomb itself and by the air. The faster the neutrons, the more collisions must they undergo until they are cooled down to ambient temperature and captured.

Furthermore, a hydrogen bomb produces ten times as many neutrons as a fission bomb of equal explosive power. Because of their high energy, the neutrons from a hydrogen bomb have a greater radiation action and reach to greater distances than the neutrons from a fission bomb before they are fully absorbed.

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Atomic weapon arsenal of the superpowers			
Name	Number	Power	Range (km)
USA			
Honest John	196	20 kt	40
Pershing	180	60-400 kt	700
Lance	42	1-100 kt	110
Sergeant	56	(low)	140
Pluton	24	15-25 kt	200
SSBS S-2	18	150 kt	3000
M-109 155-mm howitzer	326	2 kt	15
M-110 8-inch howitzer	360	(low)	15
M-115 8-inch howitzer	?	(low)	15
USSR			
SS-4 Sandal	500	1 Mt	2000
SS-5 Skean	100	1 Mt	4400
SS-20	20	(kt range)	5000
SS-lb Scud A	?	(kt range)	100
SS-lc Scud B	150	(kt range)	350
SS-12 Scaleboard	?	(Mt range)	800
Frog 7	450	(kt range)	70

(A power of 1 kt corresponds to the explosive force of 1 kiloton = 1000 t of TNT trinitrotoluene. 1 Mt = 1 megaton = 1 million t)

The neutron bomb is a combination of a nuclear fusion with a fission bomb. The ratio of fission to fusion varies slightly between the versions for the Lance missile, the 8-inch howitzer and the 155-mm howitzer. But the processes involved in the explosion are the same in each case. The nuclear fission detonates the nuclear fusion. The fusion releases many fast neutrons (therefore "neutron bomb"). This is the fundamental difference between the neutron bomb and other low-effect atomic weapons in which the fission process dominates.

NATO'S MAIN CONCERN: BLITZKRIEG BY THE SOVIETS

In the energy released by a Lance neutron bomb, the direct radiation component is six times greater than for a fission bomb of equal explosive force. For the neutron warhead of the 8-inch shell, the energy going into the neutrons is ten times greater than for a fission bomb.

The main concern of many NATO military experts is a Blitzkrieg by the Soviets or Warsaw Pact in northern West Germany. From our knowledge of Soviet armament potential it can be conjectured that such an attack, if it should actually occur, would require thousands of tanks as an advance force for such an offensive. Some military experts are of the opinion that NATO could counteract such an offensive only by using nuclear weapons. This is a point of dispute under heated discussion.

For years the military has pointed out that the use of normal atomic weapons in Western Europe would be unreasonable, especially because of their relatively high explosive force. Some of them are far more powerful than the atomic bomb that was dropped on Nagasaki at the end of the second world war, which had an explosive force of 20 kt.

Although they would certainly be capable of warding off a Soviet tank attack, the atomic weapons developed heretofore would also kill NATO soldiers and German civilians, while destroying and poisoning broad areas of Germany. The direct and residual radiation would make the occupation and habitability of the involved areas impossible for a long time.

In contrast, the military is following a different tactic with the neutron bomb: The combat soldiers are killed in their tanks, instead of the tanks themselves being destroyed. Warheads with enhanced neutron radiation offer this capability.

The radiation dose is measured in rads. 1 rad is the amount of absorbed radiation for which an energy of 100 ergs per gram of absorbing matter is released.

If nuclear weapons were to be used in a war, then they should kill the victims as quickly as possible.

An "immediate and permanent crippling", as was achieved recently in tests on apes, requires 8000 rads. Since modern tanks have a radiation protection factor of about 0.5, the tanks would have to be exposed to a direct radiation intensity of 16,000 rads.

PARALYSIS AND DEATH

A person exposed to 8000 rads of radiation becomes paralyzed within five minutes. He remains incapable of performing any tasks requiring movement, until he dies after one or two days.

3000 rads also cause paralysis within five minutes, but the victim recovers to some extent in the next half hour. However, he is still condemned to complete helplessness and dies after four to six days.

650 rads results in severe impairment of bodily functions within two hours. Medical treatment might be helpful here, but the probable outcome is a painful deterioration with bodily decay, ending with death after a couple of weeks.

These horrible effects are caused by the ionizing action of the radiation in biological tissue, produced in turn by the indirect effect of the neutrons. For example, the ionization destroys the complex organic molecules in the chromosomes, blows up the cell's nucleus, and increases the viscosity of the cell fluid and the permeability of the cell wall. It destroys cells of all types, especially those of the central nervous system. In addition, the radiation action affects the cell division process. This involves a long-term genetic damage in which the normal regeneration of cells is perturbed.

Symptoms of radiation injury are vomiting, uncontrolled movements and lamenesses. Death usually occurs by stoppage of the respiration.

The action of relatively small radiation doses can also have serious consequences. 10% of the people exposed to 150 rads die. In Hiroshima and Nagasaki, those of the survivors who had been exposed to 150 rads suffered from an above-average incidence of breast cancer.

The residents of the Marshall Islands received a radiation dose of only 14 rads during the atomic weapons tests in 1954. An above-average development of thyroid nodules, cancer and leukemia was later discovered in them. A radiation exposure of only 30 rads doubles the mutation rate in the next generation. Defective genes occur for about ten generations.

The purpose of the neutron bomb is to distribute the radiation dose over a wide area, much further than a fission bomb of equal power. That is the reason why some military experts prefer the neutron bomb.

The strongest argument in favor of the neutron bomb, from NATO's standpoint, was that the neutron bomb reduces the side effects from a nuclear explosion, i.e., the pressure, heat and radioactivity effects would be less dominant. Some citizens, especially in peace groups, abhor precisely that feature of the weapon. They see in the neutron bomb a death ray which kills the living and spares inanimate things.

Both the justification by the military and the condemnation by the peace groups are misleading.

Neutron bombs, in which fusion predominates in comparison with tactical atomic weapons, are not almost "clean" hydrogen bombs, as they are called in many reports by the mass media. The warheads up to 1 kt or the 8-inch shells have a fission:fusion distribution of approximately 50:50. The explosive charges for the Lance missile have about 40% fission and 60% fusion. The 2-kt warhead for the 8-inch shell has about 70 to 75% fusion. In other words, these weapons are somewhat "dirtier" (fission predominates) than is assumed by many of their proponents and opponents.

PINPOINT AIMING ACCURACY

The idea that the neutron bomb makes a nuclear war manageable is based on the supposition that it takes two to have a "limited nuclear war." The Soviet Union seems to have neither the capability nor the will to play such a role. Of its 3500 tactical atomic weapons that stand ready for an attack in Europe (there are 7000 in NATO), most probably have an explosive force of more than 20 kt.

About 600 long-range guided missiles have explosive forces of between 500 kt and 3 Mt. The smallest of their weapons has 5 kt. Soviet atomic guided missiles are far less accurate than those of the Americans. Thus, it is difficult, if not impossible, for the Soviets to carry out targeted attacks in this manner, as are necessary for an effective "limitation of damage."

In the Soviet analyses of warfare, the fine distinctions often made by the American military on the subject of "tactical nuclear wars" do not seem too clear. In the Soviet literature there is usually no distinction made between a tactical and a general atomic war.

Terms such as "pinpoint aiming accuracy" or "selected targets" appear nowhere in Soviet plans for a tactical nuclear war. Massed barrage fire, tearing holes in NATO's defenses and then breaking through with heavy tanks (whose construction and surface materials provide some protection against nuclear effects); these appear to be the Soviet's actions for a tactical nuclear attack.

If the NATO neutron bombs are employed against tanks, the Soviets will most likely strike back with their own atomic weapons. According to an American study of Soviet military actions, "a series of counterblows is expected, including nuclear attacks, if the initial tank breakthrough is unsuccessful."

The Soviets would hardly be upset about the "side effects" on the West German population. Even if they were, the large effect and poor aim of their weapons would make it impossible for them to do anything about the inevitable consequences.

Even before a Soviet retaliation, much damage would already be done by NATO's neutron bombs, despite the fact that the pressure, heat and radioactivity from the individual bombs are limited. According to a statement by the American Secretary of Defense in 1977, if nuclear weapons should be used in Europe then "such an action should motivate the Soviet Union to terminate the conflict at once. The firmness of such an action and the shock effect should move the Soviet Union to carefully consider their activities."

As a deterrent, NATO would have to stop a few dozen tanks. To make a lasting impression on the Kremlin leaders, yet a few more would be necessary. But how many more? During an offensive, Soviet tanks roll forward in two attack rows. The tanks in the first row have 75 m of separation between them in non-nuclear situations, 100 m in nuclear situations. The second row of tanks rolls along 3 km behind the first. The Warsaw Pact has 20,000 tanks ready for a military contest in Central Europe, and it is there that the first battle in a war between the two superpowers would probably take place.

However, the war leaders' expectations that the neutron bomb would cause hardly any secondary damage depend on the bomb being used in a closely targeted manner, if possible only in a single attack. But if NATO wants to stop an effective fraction of the first tank front without molesting any tanks in the second front, then such an action would require a few hundred such bombs.

Under these circumstances, the induced radiation might damage the soil considerably. The number of persons dead and condemned to death would be enormously high in any case, even if the nuclear war were to remain highly limited.

Furthermore, a reasonable use of the neutron bomb is rendered doubtful by basic military considerations. A tank covered with a few millimeters of a foil of material containing boron can reduce the penetration of neutrons by half. A few centimeters of a material containing hydrogen have the same effect.

A centimeter or less of water could protect the tank just as effectively as if it were standing behind a hill. Such measures would make the Soviet tanks somewhat heavier and thus also increase the weight-to-performance ratio.

UNUSUALLY EXPENSIVE WEAPON

Neutron bombs are extremely expensive. The warhead for the 8-inch shell costs about 750,000 dollars. Instead of two 8-inch shells with neutron warheads, the U.S. could buy three M-60 tanks, about 50 antitank shells and more than 5500 conventional artillery shells. That means that if the U.S. were to invest heavily in neutron bombs, NATO would be equipped with an unusually costly weapon which might perhaps never be used.

The American Secretary of Defense justifies the neutron bomb despite its low military battleworthiness and its high cost: "If the NATO arsenal contains the neutron weapon also, then enemy nations should know that NATO can defend itself with small damage to itself. That might deter an attack". The basic idea is that the Soviets assume NATO would rather use neutron bombs than the older nuclear weapons in which fission predominates.

Three remarks might be added here:

- Even without neutron bombs, the Soviets would be taking a severe risk by an attack, because of the Americans' refusal to agree "not to strike the first blow" with nuclear weapons.
- If NATO uses neutron bombs, enormous damage would result, even without allowing for the damage resulting from the inevitable Soviet counterattack.
- Without going into the question further here, there is no reason to assume that NATO would be incapable of defending itself without using atomic weapons.

The strengths of the conventional weapons of NATO and the Warsaw Pact are probably about the same. The highly advertised superiority of the Warsaw Pact

in tanks is counterbalanced by the American superiority in tank defense, particularly the precise guided missiles.

Important arguments against the neutron bomb:

- The neutron bomb is not nearly as "clean" a weapon as claimed by its proponents.
- It is dangerous insofar as its development leads to the erroneous view that a nuclear war could be conducted in a safely limited and controlled manner.
- The neutron bomb is not more humane than chemical bombs whose first use has already been forbidden for a long time by international agreements.
- The neutron bomb hardly has any greater military usefulness than any other low-effect nuclear weapon.
- To the extent that the USSR figures on the use of neutron bombs by the U.S. in the event of a war, a sudden nuclear blow by the Soviet is encouraged in extremely stressful situations. That might perhaps be the motivation for a European war.

In any case, there is no reason to assume that the neutron bomb would in any way reduce the probability of a tactical atomic attack expanding into an all-out atomic war, or that the use of neutron bombs would mitigate the Soviet counterblow.

On the whole, there are many strong arguments against the neutron bomb and little speaking in its favor.

How Does the Neutron Bomb Work?

:as a fission bomb exploits the effect that a heavy nucleus splits into two nuclei with release of energy, in hydrogen fusion the lightest element, hyd:is fused to form the second lightest element, helium, a process by which the tains its energy.

rthly practice, however, one does not use the lightest hydrogen isotope witlnumber 1. Instead, for technical reasons one fuses deuterium, the hydisotope with mass number 2, and tritium, the only radioactive hydrogen isotth mass number 3, to form helium-4. One neutron is thereby released:

$$D + T \rightarrow {}^{4}He + n + 17.6 \text{ MeV}$$

usion of deuterium with deuterium to form ^{3}He or T is also possible:

$$D + D \begin{cases} {}^{3}He + n \\ T + p \end{cases}$$

The for using deuterium and tritium is that a much lower temperature is thenred for the fusion process.

er, deuterium and tritium are not present from the beginning in a hydromb. The tritium is produced during the explosion itself by allowing the ns that are released during the fission of the detonator (i.e., the atomb) to act on the isotope ^{6}Li. In addition to an alpha particle (helium nucla tritium nucleus is also formed:

$$^{6}Li + {}^{1}n \rightarrow {}^{4}He + {}^{3}H$$

the metal lithium is used as a potential nuclide for the production of t:, the deuterium can be bound chemically with the the lithium. Thus, thisum deuteride compound (LiD) is used. LiD is a white salt-like substance which significantly higher density than the liquid mixture of hydrogen isotc

dingly, a hydrogen bomb is built as follows: The lithium deuteride is plas a shell around the fission bomb serving as the detonator. When the fissimb is set off, a temperature of several hundred million degrees Kelvin is prcdin the interior for a period of about a microsecond. At the same

time, the fission releases neutrons which then release tritium from the lithium in the surrounding shell of lithium deuteride. Because of the high temperature, the tritium fuses with the deuterium to form helium and additional neutrons, which in turn release more tritium from another lithium nucleus.

IN ANY CASE, AN ATOMIC BOMB AS DETONATOR

The entire configuration holds together until the temperature in the interior has dropped below the critical threshold of about 50 million degrees Kelvin. Then no more nuclear fusions occur. The reason for this temperature drop: Due to the high temperature, the bomb flies apart, thus attains a lower density and also emits thermal radiation.

The first hydrogen bomb, which was exploded on 2 November 1952 on the Bikini Atoll, still contained a mixture of liquid deuterium and tritium which had to be cooled down to 20 degrees Kelvin, a temperature below the boiling point of liquid hydrogen.

The possibility of using lithium-6 instead of tritium apparently occurred first to the Soviets. In any case, the first transportable hydrogen bomb was set off by the Soviet side. In that bomb, lithium deuteride was evidently used for the first time as a material for the fusion.

A hydrogen bomb always needs a fission bomb as detonator. The major portion of the radioactivity in the explosion of a hydrogen bomb comes from the explosion of the atomic bomb, i.e., from the radioactive decay of the fission products. The hydrogen bomb itself, i.e., the nuclear fusion of hydrogen into helium, produces very little radioactivity. It is caused primarily by the neutrons that are released during the fusion process, which then activate the surrounding material. No radioactivity is produced in the fusion of deuterium and tritium themselves.

If one builds a very large hydrogen bomb, then the amount of radioactivity released by the fission bomb is comparatively small relative to the bomb's effect. If one chooses a small hydrogen bomb, i.e., low explosive power up to one megaton of conventional TNT explosive (trinitrotoluene), then the contribution of fission products from the fission bomb is relatively high.

Thus, a "clean" hydrogen bomb in which the contribution of radioactivity to the destructive action is small is always a bomb of extremely large explosive power. A "dirty" hydrogen bomb is a bomb of smaller explosive power.

In ɪiple, the absolute amount of radioactivity for a dirty hydrogen bomb is jas great as for a clean hydrogen bomb, since the detonator (the atomic bomb)s the same size in both cases.

ɥig bw a hydrogen bomb works, one can get an idea of how a neutron bomb might ibL:

Fist: must be considered that a neutron bomb would certainly have to be a hydrobomb. For the lethal power of a neutron bomb derives from fast neutrons, fast neutrons with an energy of 14 MeV (million electron-volts) are releasıly in a hydrogen bomb explosion.

Sinceutron bomb is to have an effect only in a small radius, the proportionydrogen fusion must be relatively small. Thus, we are dealing with a minlrogen bomb. In addition, no large amount of radioactivity is to be rele Therefore, the atomic bomb required as a detonator must likewise be a mini .c bomb.

But a: bombs cannot be made arbitrarily small. The "critical mass" imposes a : limit. A certain minimum amount of fissile material is needed to set off ain reaction. Of the neutrons released in one fission event, at least one ıtrigger another fission event.

Neutrcor such secondary fissions can be lost by escaping into the outside space or byng absorbed, thus producing nuclear reactions, i.e., transformations of elementshout fission.

Accordy, important quantities for the "yield" of a chain reaction are the densitythe fissile material and the interaction cross-section.

The crsection, descriptively the size of the "target disk" for an approachingtron, is a specific area for a given nuclide. The surface area unit of 1 bawas defined for it: 1 b = 10^{-28} m^2. However, the barn is no longer permible under the new units law.

There atwo ways to construct a mini atomic bomb. The first makes use of a fissile maial having a very small critical mass. A smallest possible critical maseans thc the probability for fission by neutrons must be very high. The crs-sectic of this nuclide for fission by neutrons must be as large as possible. he large the cross-section, the smaller the critical mass.

Of the nucides th can be considered, two are being produced at present in the United Stats: curi-245 and californium-251.

Both are very long-lived nuclides. Curium-245 has a half-life of almost 10,000 years. Californium-251 has a half-life of almost 1000 years. The cross-sections for neutron fission are about $2 \times 10^{-25}\ m^2$ for curium-245 and $4.3 \times 10^{-25}\ cm^2$ for californium-251, the latter being the largest cross-section yet. Thus, the cross-section is more than eight times larger for californium than for uranium-235.

SMALL CRITICAL MASS BY EXOTIC ISOTOPES

Accordingly, the critical mass can be kept eight times smaller for californium than for uranium and even plutonium. That means that the critical mass (the minimum mass to be able to use a mini atomic bomb as detonator for a mini hydrogen bomb) might be in the range of a few hundred grams.

Both nuclides - californium-251 and curium-245 - are now being produced in the U.S. in larger amounts by irradiating uranium and plutonium or americium. However, the two elements, californium-251 and curium-245, are not produced in pure form, but rather have to be separated from accompanying isotopes (four to five different isotopes are produced in each instance) in an isotope separation process and enriched.

Thus, it seems questionable whether these two isotopes are already being produced in sufficient amounts in the United States to change over an entire weapons technology to neutron bombs. Of course, it also does not seem entirely impossible when we consider that many production reactors have been making plutonium for weapons production and are being converted to the production of these nuclides for neutron bombs. (Production reactors supply no energy for peaceful application of nuclear energy, but rather produce plutonium for weapons purposes.)

However, we can rule out the possibility that nuclear power plants are being used to produce these exotic californium and curium isotopes. Firstly, the neutron flux in power reactors is relatively low, so that extremely long irradiation times would be needed. Secondly, modern power reactors are designed for the generation of energy and have no facilities for irradiation of foreign substances.

The second possibility for an atomic detonator in a neutron bomb: One might exploit the fact that the critical mass of a nuclide depends on its density.

If one could successfully use omnidirectional pressure to produce an extremely high density in the plutonium (about 17 grams/cm^3 for the plutonium-gallium alloys used in modern nuclear weapons technology) and increase that density by twice or more in a few nanoseconds, perhaps by means of a shock wave, then the

critical mass could be reduced considerably. It would be possible to reduce it to the range of a few hundred grams by using a nuclide that has a large cross-section for neutrons. For example, plutonium-241 has a smaller critical mass than plutonium-239 which is now being used in tactical atomic weapons.

A shock wave might be produced, for example, by means of conventional explosives. Conventional explosive lies in a ring configuration around the fission bomb, i.e., as a third layer over the lithium deuteride. Upon detonation, the shock wave is directed toward the fission bomb on the inside. Its effect is thus to compress the lithium deuteride to a higher density, thereby raising the utilization factor of the utilized substance.

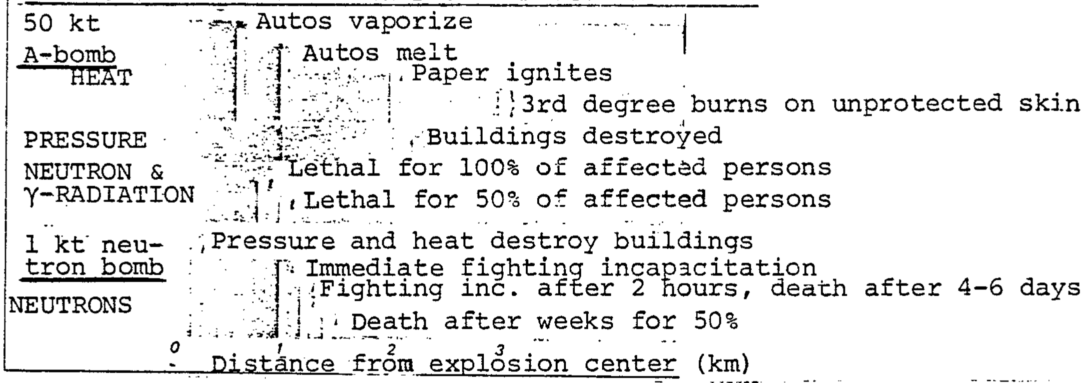
STILL NO "CLEAN" BOMB

Such a neutron bomb has three concentric layers: the denotating atomic bomb in the middle, a shell of lithium deuteride around it, and conventional explosive on the outside. A similar principle was already applied in nuclear weapons by placing a steel shell around the actual atomic bomb to prevent the configuration from flying apart too quickly.

The "cleanest" neutron bomb might be built by using laser nuclear fusion. That could be accomplished, for example, by bombarding a $(D,T)_2$ drop of liquid hydrogen on all sides by a laser beam of extremely high intensity. Due to the interaction of the laser beam with the outer hydrogen atoms of the drop, the inner hydrogen core could be heated up to the temperature of about 40 million degrees Kelvin required for fusion. There would then be no need for a fission bomb as a heating source.

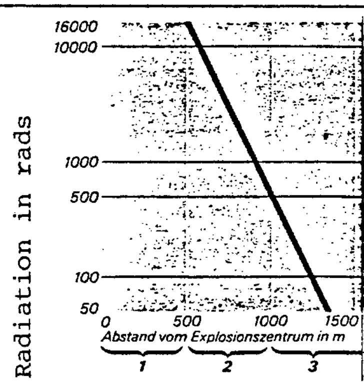
Despite great efforts in the U.S., laser nuclear fusion does not appear to have been realized yet, not even in the laboratory. But an absolute statement to that effect is not possible because of the secrecy.

ENHANCED RADIATION INSTEAD OF PRESSURE AND HEAT



A comparison of the effects of a neutron bomb and an atomic bomb of the Hiroshima type shows that radiation is almost the only effect of the neutron bomb. According to military ideas, the neutron bomb should stop a tank attack. "Immediate fighting incapacitation" (to a distance of 1 km) means immediate paralysis and death after a few hours for all persons in that region.

RADIATION RANGES FOR EXPLOSION OF A 1 kt NEUTRON BOMB



Distance from explosion center in m

1 16,000 rads and more
Range of "militarily desired" effect

2 500-16,000 rads
Range of lethal radiation for persons without protective shielding

3 50-500 rads
Range of radiation sickness for persons without protective shielding

How Do Neutron Rays Act on Living Matter?

Neutrons activate any element. That means that any element becomes radioactive by capturing neutrons. This activation is very slight for a neutron bomb. The main effect comes from the reaction between the fast neutrons (slowed down by water in the body) and hydrogen atoms in the complicated compounds of living matter.

They collide elastically with those hydrogen atoms. A hydrogen atom, which has the same mass as a neutron, is shot away from its position. This forms molecular radicals which no longer have the biological functions of the normal enzymes. When an organic molecule has lost one or more hydrogen atoms, this biologically active substance can no longer carry out its function, which can result in sickness and death.

But biological tissue is not destroyed only by direct action of the neutrons; recoil protons have the same effect. One recoil proton (from the collision with 14-Mev neutrons) is enough to form about a million ion pairs. The heavy elements that are present in the biological system, such as iron or sodium, are also activated, but that effect is practically zero.

Almost all materials are relatively transparent to fast neutrons. They penetrate concrete walls, steel and lead. Even a thick lead plate is almost as transparent for fast neutrons as window glass is for visible light. Thus, they also penetrate any tank. Inside the tank they impinge on organic material and exert their destructive effect.

The best protection against a neutron bomb would perhaps be the interior of a swimming pool. The surrounding water in a layer about 30 cm thick holds back the neutrons and recoil protons. When a recoil proton has released its kinetic energy by undergoing elastic collisions, it has become a "normal" hydrogen atom.

If a tank were surrounded with a water layer or with a paraffin layer about 10 cm thick, then the fast neutrons from the neutron bomb would be slowed down by the hydrogen atoms in that layer. Then the iron shell would no longer be transparent for these "thermal" neutrons.

Neutron Therapy

Neutron therapy to combat cancer is based on the same effect as the action of a neutron bomb. Only here the action of the neutrons is purposely restricted to certain areas. In the same way, the neutrons are produced by fusing deuterium

and tritium into helium.

Of course, the reaction is not initiated here by an atomic detonator to produce the required temperatures of 100 million degrees. Rather, the deuterons are accelerated to a velocity which corresponds to that temperature. Deuterium is ionized in an ionization chamber, thereby obtaining deuterons which are then brought to the required velocity (an energy of about 100 kiloelectron-volts [keV]) in a small circular accelerator.

These deuterons impact onto a target, made for example of titanium hydride with the hydrogen isotope tritium. Through the D+T reaction they then produce neutrons which are guided onto the cancerous tumor to be destroyed. An example of such a device is the KARIN (Karlsruhe Ring Neutron Source) which is being used in the Heidelberg Cancer Research Center.